SOIL AND CLIMATIC FACTORS RELATED TO THE GROWTH OF LONGLEAF PINE

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Forest Service, U. S. Department of Agriculture

OCCASIONAL PAPER 132

December 1953

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The purpose of this investigation was to find a means of predicting site quality for stands of longleaf pine (Pinus palustris Mill.) in terms of the soil and climatic factors that may be related to tree growth. In areas where the land is cutover or abandoned, the conventional means of estimating site quality--the trees themselves--is not present. Therefore, it is desirable to have a method that is not dependent on the presence of trees, but rather is based on permanent mappable features of the area such as the climate and the physical properties of the soil.

The study showed that in the Gulf Coastal Plain region longleaf site quality--in terms of the height of dominant trees at 50 years of age--can be predicted from two factors. The first of these is the amount of rainfall that the site receives during the first six months of the year. The second is the depth of soil to the least permeable horizon.

Since both soil depth and amount of rainfall can readily be determined, the study findings can be applied by practical land managers who wish to evaluate their sites. Readers who are interested only in this phase of the study may wish to turn directly to the section on field application, pages 9-12.

1/ Condensed from a dissertation presented in partial fulfillment of the requirements for the Ph. D. degree at Duke University, Durham, North Carolina. This study was conducted under the direction of T. S. Coile and F. X. Schumacher of the School of Forestry, Duke University.

CLIMATE AND SOILS

The band of longleaf pine from Mississippi to Texas is approximately fifty miles wide. The climate of this narrow strip is relatively uniform, being temperate to subtropical and subhumid (6) 2/. Rainfall for the first six months of the year increases from a low of 25 inches in Texas to a high of 33 inches in southern Mississippi and southeastern Louisiana. The growing season averages 250 days.

During Cretaceous times, all this area was a shallow sea which retreated near the end of the era. The sediments of the Coastal Plain, which were brought down by streamflow or left behind by the retreating sea, are slightly consolidated sands, clays, and marls, and dip gently seaward.

In those parts of the Coastal Plain where longleaf pine is found, the most prominent soil series are in the Norfolk-Ruston and Caddo-Beauregard catenas (5). All series in these catenas belong to the red and yellow podzolic soils. These soils, which are products of podzolization and laterization, are characteristic of warm-temperate, humid regions. Their internal drainage ranges from good to poor.

METHODOLOGY

During the past quarter century, numerous investigations have been made in the United States to describe or predict site quality of land for tree growth in terms of soil characteristics. These investigations have followed two general lines: one approach has been the study of chemical properties of the soil; the other approach has been the study of physical properties of the soil profile or particular horizons. Thus far, it has been in the realm of physical properties that the most usable correlations between site quality and soil have been found. Consequently, the soil phase of this study was, in the main, restricted to physical characteristics. All the literature pertinent to the subject has been brought together in a thorough and comprehensive review by Coile (1).

2/ Underscored numbers in parentheses refer to Literature Cited, page 12.

For this study a circular sample plot, 0.2-acre in size, was taken in each of 143 separate stands of longleaf pine from Mississippi to the western limit of the species' range in east Texas (fig. 1). Stands which were selected for study showed evidence that the dominants were of uniform age, had grown under conditions of good stocking, and had never been suppressed (fig. 2). No stand was included unless it was at least twenty years old. Trees younger than this vary considerably in height growth and probably do not fully reflect site and competition conditions. Stands of similar age and soil type were not taken closer than one mile from each other.

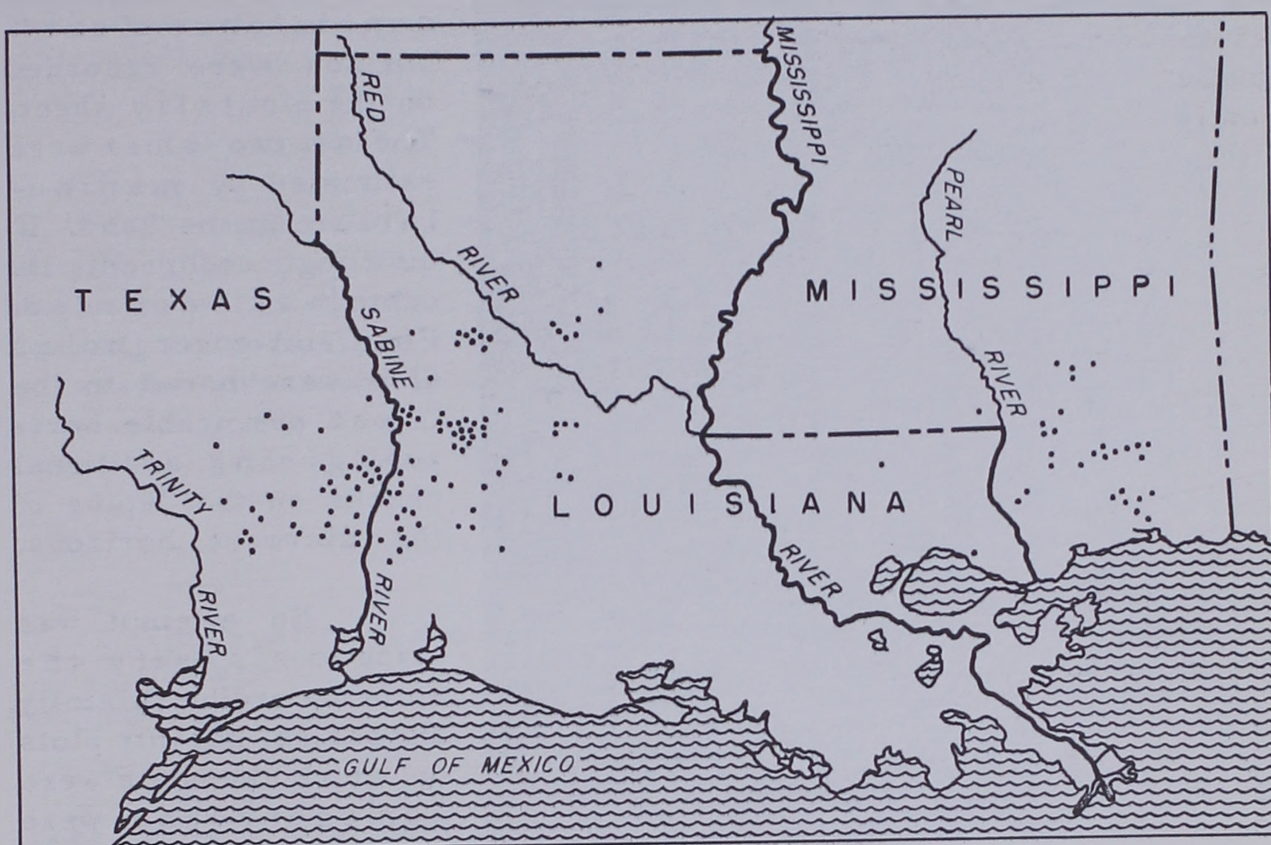

Figure 1.--Location of sample plots.

For eight dominant trees on each plot, the diameters at breast height were measured to the nearest one-tenth inch, and the ages at breast height were determined with an increment borer. On the first 84 plots, two of the eight trees were also bored at one foot above ground, to obtain age at stump height. The total height of each of the eight trees was measured to the nearest foot with an Abney level.

Soils data were obtained from four post holes dug on each plot in approximately cardinal directions from the plot center. The holes

Figure 2. --A well-stocked even-aged longleaf stand typical of many sampled.

were sunk to a depth of forty inches or to the C horizon if it occurred sooner. A composite sample of each horizon was collected for laboratory analysis. The thickness, internal drainage, texture, and consistence of each horizon were recorded on the plot tally sheet. The last two values were estimated by manipulation in the hand. If mottling occurred, its depth was recorded. Four soil auger holes also were bored to the least permeable horizon, giving additional checks on the depths of the different horizons.

No attempt was made to classify the soils according to family and series, but only plots on which the soils were homogeneous were sampled.

Four topographic features were recorded: position on slope, percent slope, class of surface drainage (a reflection of position on slope and percent slope), and aspect. For areas with no slope, the aspect was recorded as zero.

In the laboratory analyses, both the surface soil and the least permeable horizon were examined. Moisture equivalent determinations were made on both these horizons. The xylene equivalent was determined for the least permeable horizon only. For surface soil, the A_2 horizon was used, since the organic matter present in the A_1 gives higher

moisture equivalent values than the same soil without organic matter. This is a justifiable procedure when one considers that the quantity of organic matter in Gulf Coastal Plain soils varies with the age of the stand. Indeed, organic matter may be lacking on recently abandoned or barren land--the very places where it is most useful to be able to predict site in terms of permanent soil features.

Imbibitional water value (the numerical difference between moisture equivalent and xylene equivalent) was determined for the least permeable horizon. The imbibitional value is a measure of the kind and amount of clay present in the soil.

ANALYSIS OF DATA

The method of least squares was used for all statistical determinations. The initial step in the statistical analysis was to express the height in feet of the dominant stand in its logarithmic equivalent. Equating the logarithm of height to a constant plus the reciprocal of age resolves the sigmoid-shaped growth curve of longleaf pine into a more manageable linear expression (3). Once the general form of the equation is decided upon, the regression can be written as follows:

$$Y = b_o + b_1x_1 + b_2x_2 + b_3x_3 + \dots + b_nx_n$$

This system of analysis, together with the solution of the variables and their respective variances, is described by Schumacher and Chapman (4).

Since longleaf pine lives an unpredictable period of years in the grass stage, it was decided to relegate measurements of age to stump height rather than introduce an average age from seed to breast height. Age at stump height was obtained by adding two years to the age at breast height; it was computed from the 84 plots in which age at stump height and at breast height were determined.

Longleaf pine, in contrast to other southern pines, often appears in rather open, savannah-like stands (fig. 3). Under these conditions, it was thought, tree heights might be significantly lower than in comparable well-stocked stands. To test this hypothesis for these data, a separate regression was set up in which stand density per acre was expressed in terms of tree size, age, and numbers, and in combinations of these factors. The resulting equation was used to calculate the stand density of each of the 143 plots.

Figure 3.--Longleaf pine often grows in open, savannah-like stands. In this study, however, stand density did not significantly influence height growth.

Since the range of plots extends from eastern Mississippi into Texas, it was necessary to consider possible environmental effects that might be correlated with height growth and longitude. Rather than employ the actual degrees of longitude as a variable, it was decided to use rainfall, which decreases in all directions from a center near east-central Louisiana. The rainfall variable was further refined by using the first six months' rainfall, since presumably this is the most critical moisture period in terms of height growth for southern pine.

Ralston's earlier study of site index of longleaf pine in the Atlantic Coastal Plain showed that topographic position is a significant factor in determining height growth (2). Typically, this factor is used to divide the data into four classes of surface drainage: excessive, good, imperfect, and poor. Of the 143 plots measured in the present study, however, 133 were classed as having good drainage, and therefore only that one drainage class was recognized in the analysis.

In Ralston's work, depth to mottling also was a significant variable. In the data presented here, the scarcity of imperfectly or poorly drained sites virtually precluded any considerations of depths to mottling, since mottling rarely occurs in well-drained profiles.

RESULTS

The statistical solution of the data showed the amount of January-June precipitation to be more important than any other variable. Of the soil factors measured, depth to the least permeable horizon was the most significant.

The preliminary regression was solved by removing first the constant and then age. All subsequent variables were removed in the order that would account for the greatest remaining sum of squares each time. The results of this regression showed the effect of rainfall to be so great that the soil variables showed no significant effect on height growth. Therefore a second regression was solved in which rainfall was not eliminated until last. Even so, the effect of rainfall completely overshadowed the effect of the significant soil variables.

Two more regressions were solved, one excluding rainfall and the other using the joint variation in rainfall and soil depth. The latter of these showed the most practical results and was used for calculating table 1 (page 11).

In the final regression, the following variables were significant:

1. Reciprocal of age
2. Depth to least permeable horizon times rainfall
3. Depth to least permeable horizon.

When solved by least squares for its appropriate coefficients, the equation for tree height derived from the final regression reads as follows:

$$\text{Log of tree height (in feet)} = 1.9995 - \frac{6.492}{\text{Age}} + \text{DLP}\,[0.0002636(\text{R}) - 0.006734]$$

where: DLP = Depth to least permeable horizon in inches
R = First six months' rainfall in inches.

The error of estimate is 8.26 percent. After the age is equated to 50 years, the equation is given in terms of site index by the following expression (graphically illustrated by fig. 4):

$$\text{Log of site index} = 1.8697 + 0.0002636(\text{R})(\text{DLP}) - 0.006734(\text{DLP})$$

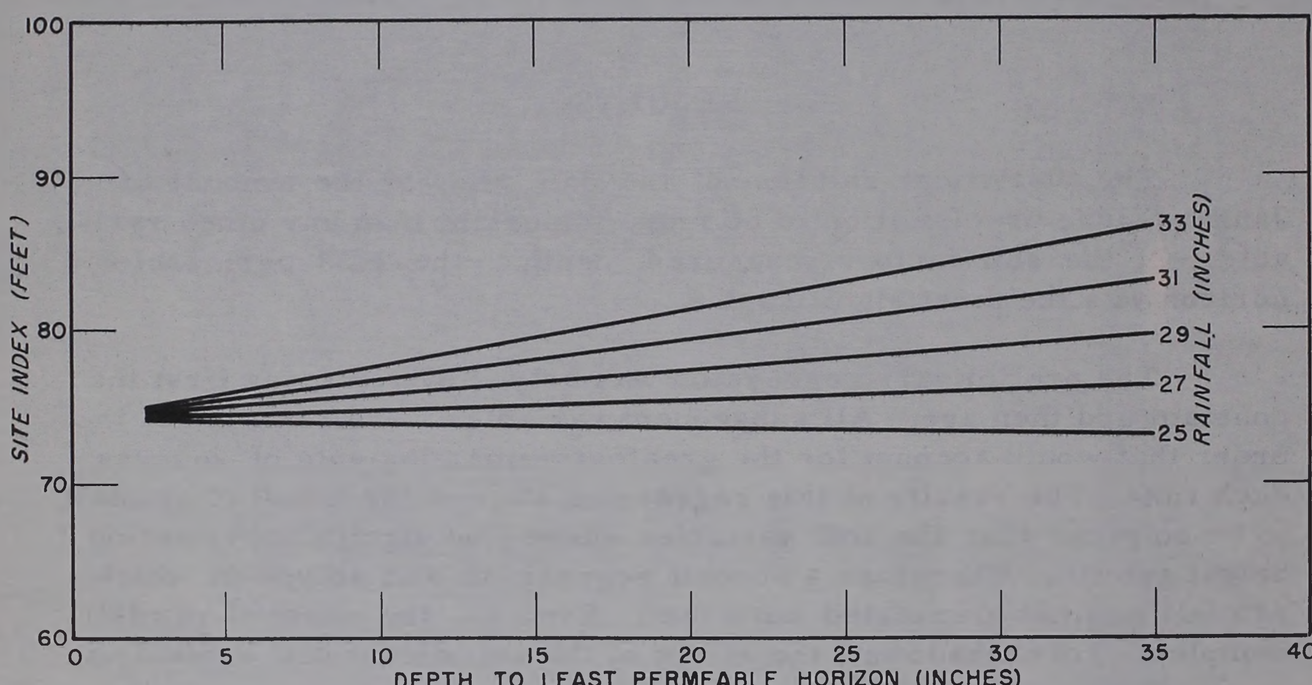

Figure 4.--Site index plotted over depth to least permeable horizon, by rainfall classes.

Stand density, either with or without rainfall, did not prove significant in any of the regression schemes. This would indicate that there was no significant variation of height growth within the range of stocking measured.

Moisture equivalent variables of the surface soil proved to be significant at the five-percent level when rainfall variables were omitted. In the presence of rainfall variables, all soil moisture variables and their interactions became nonsignificant. This lack of correlation was due in part to the rather limited variation of these moisture values.

Depth to the least permeable horizon was not significant in the first two regressions. However, in the third regression in which rainfall was omitted, depth was significant at the five-percent confidence level. In the fourth regression, with rainfall interactions, depth became significant at the one-percent level.

Rainfall is significant regardless of the time of its removal from the regression. It is perplexing that increase in rainfall should be so strongly correlated with improvement in site, particularly when one considers that the average first six months' rainfall at the western limit of longleaf growth in the Gulf Coastal Plain is higher than that of the Atlantic Coastal Plain. Hence, average rainfall can scarcely be considered a limiting factor in this area. It is likewise highly improbable that a range of only eight inches of rainfall (in six months) could bring about any marked changes in soil properties capable of accounting for the range of site indices encountered. For these reasons, it is highly doubtful that any cause-and-effect relation between rainfall and site is being displayed here. Instead, rainfall would seem to be strongly correlated with some controlling climatic variable as yet not measured directly.

Rainfall times depth to the least permeable horizon was highly significant at five percent in the fourth regression, indicating an interaction between amount of moisture and growing space for roots.

FIELD APPLICATION OF RESULTS

The results of this study may readily be used to find the site index of any given area in the longleaf pine belt of the Gulf Coastal Plain. The procedure is as follows:

1. Determine the average amount of rainfall that the area receives during the first six months of the year. For all practical purposes, this can be done merely by locating the area on the map containing the rainfall contour lines (fig. 5).

2. Bore enough holes in the soil on the area to determine the average depth to the least permeable soil horizon.

3. Read the site index from table 1.

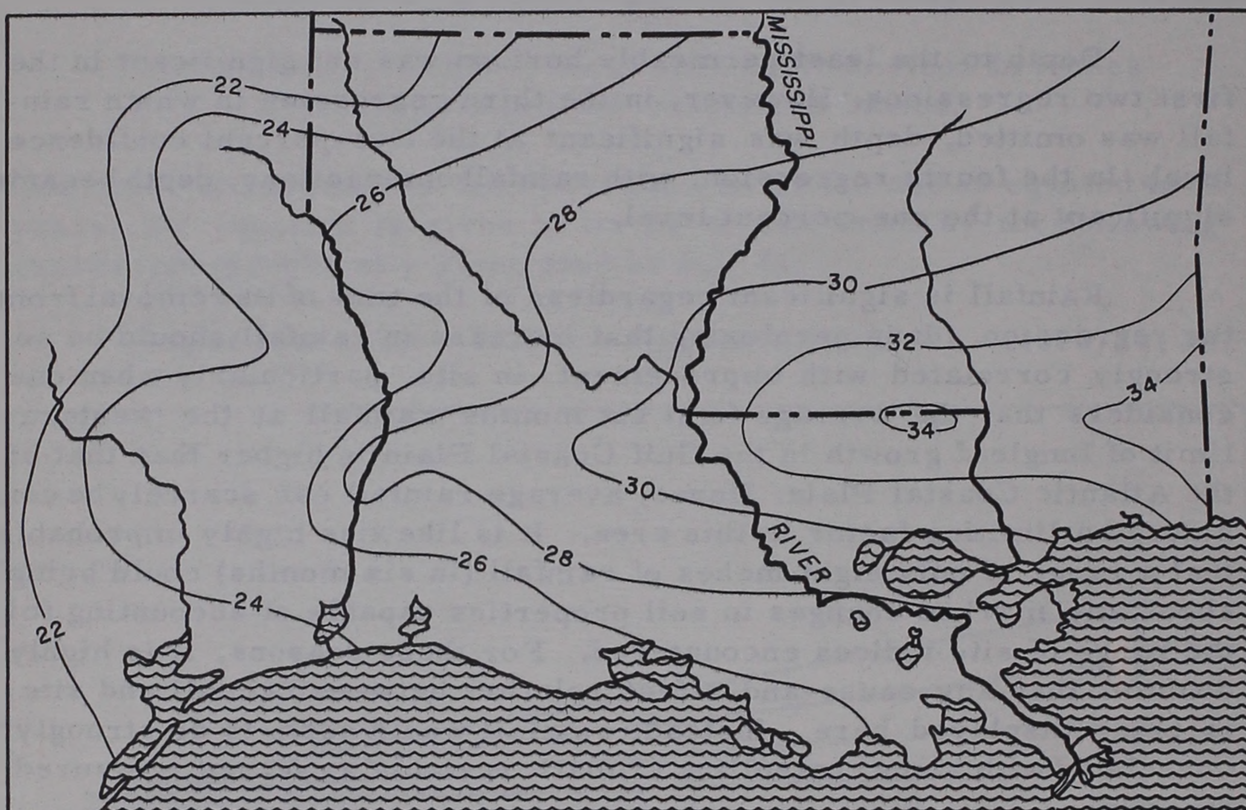

Figure 5. --Average rainfall in inches, January through June (6).

For example, on an area where the depth to the least permeable layer is about 22 inches, and where January-June rainfall averages from 28 to 30 inches, the site index is 77. That is, dominant longleaf pines can be expected to reach 77 feet in height by the time they are 50 years of age. It must be remembered, however, that the heights predicted by table 1 apply only to even-aged, unsuppressed stands. The figures do not hold for stands that develop under an existing forest canopy.

Table 1. --Site index of longleaf 1/

Depth to least permeable horizon (inches)	Rainfall, January through June				
	24 - 26 inches	26 - 28 inches	28 - 30 inches	30 - 32 inches	32 - 34 inches
	- - - - - - - - Site index - - - - - - - -				
0-5	74	74	74	75	75
6-10	74	74	75	76	77
11-15	73	74	76	77	78
16-20	73	75	76	78	80
21-25	73	75	77	80	82
26-30	72	75	78	81	84
31-35	72	75	79	82	85
36+	72	75	80	83	87

1/ Average total height in feet of dominant trees at age 50 years.

The main problem in applying these instructions is to take enough depth measurements on a site to truly know the average depth to the least permeable horizon. There may also be some difficulty, at times, in identifying the least permeable horizon.

If the area in question is fairly flat, or if it is of uniform slope, four or five holes per acre might well suffice, especially if the depth measurements do not vary more than a few inches from hole to hole. If the topography is rolling, one would expect marked changes in subsoil depth between the bottom and the top of a slope. On long, sustained slopes where wide areas are comparable, different productive capacities can be separated without much difficulty. In sharply rolling topography such as occurs in the upper Coastal Plain, the average of the measurements on lower, middle, and upper slopes will have to suffice.

In areas where the least permeable horizon is a heavy clay, it is easily distinguished from the more permeable horizons that overlie it. Often, however, the least permeable horizon found under longleaf stands is not markedly different in texture from the surrounding horizons. In such cases slight changes in color may help to tell one ho-

rizon from the next, and if the soil is rubbed between thumb and forefinger the least permeable horizon will feel finer in texture than the other horizons.

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